Wisconsin Energy Institute
UNIVERSITY OF WISCONSIN–MADISON

# Pathways and Transformations of Energy and Matter

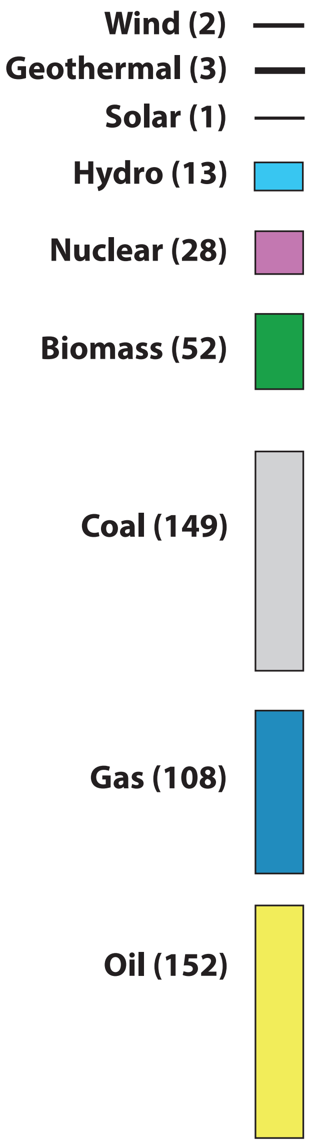
## A global sustainability context, with bioenergy as a case-study

John M. Greenler, Ph.D.

Integrated Biological Sciences – Summer Research Program

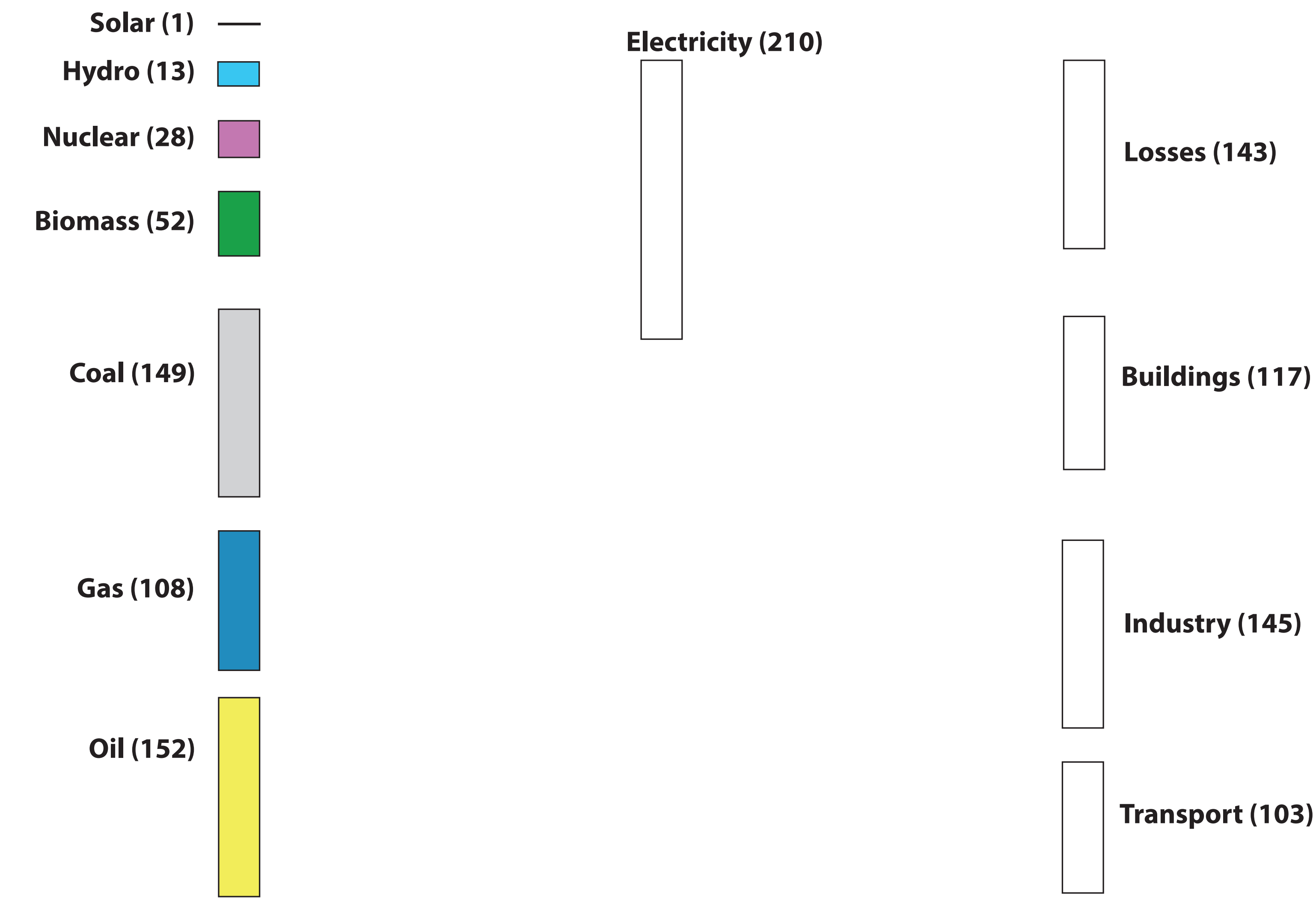
June 7, 2016

# Global Energy:
## Sources, Uses, and Paths




Units are in Exajoules (EJ) per year

**Global flows of energy associated with human activities**
(Adapted from LLNC World Energy Flow in 2011)

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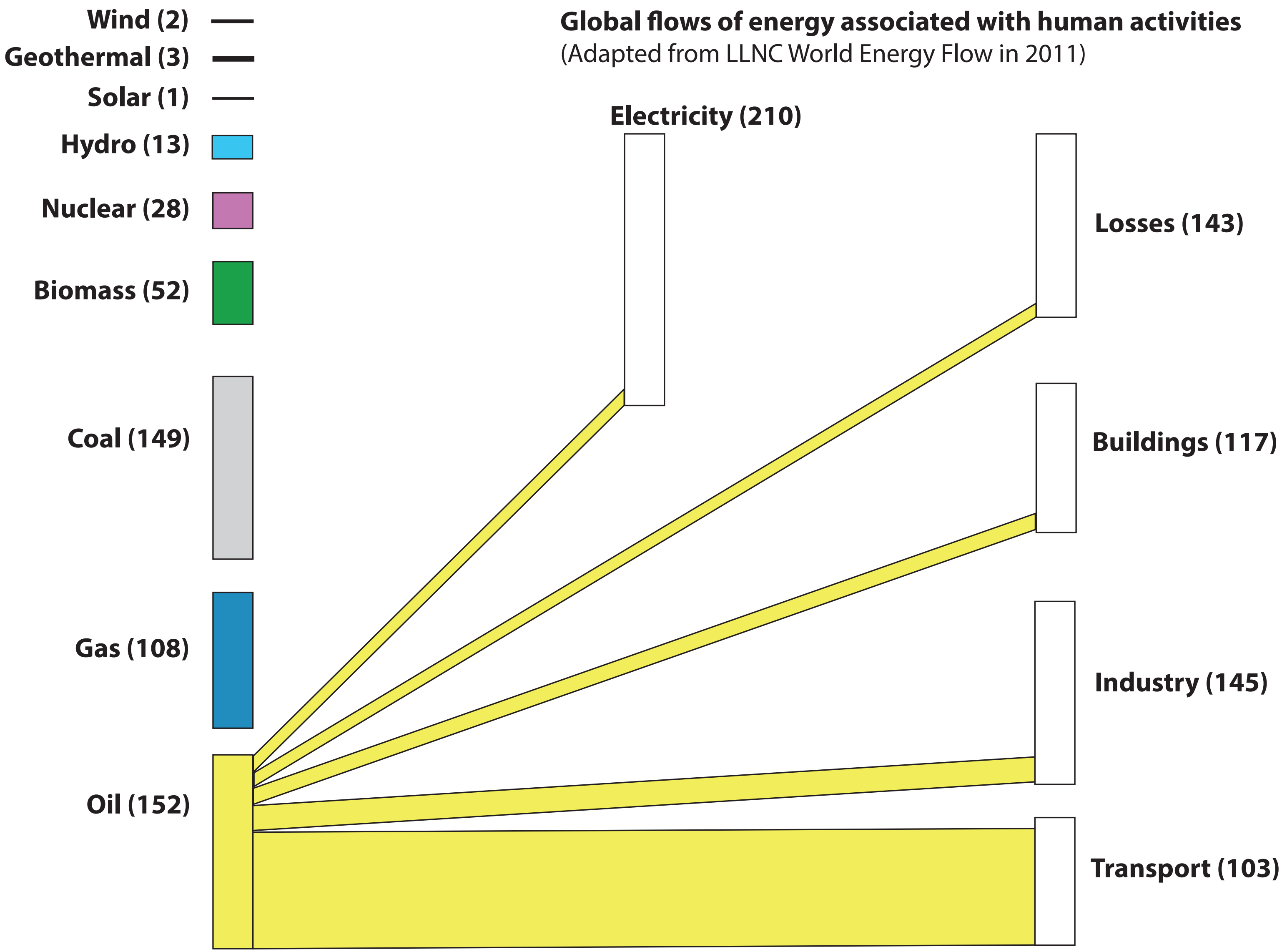


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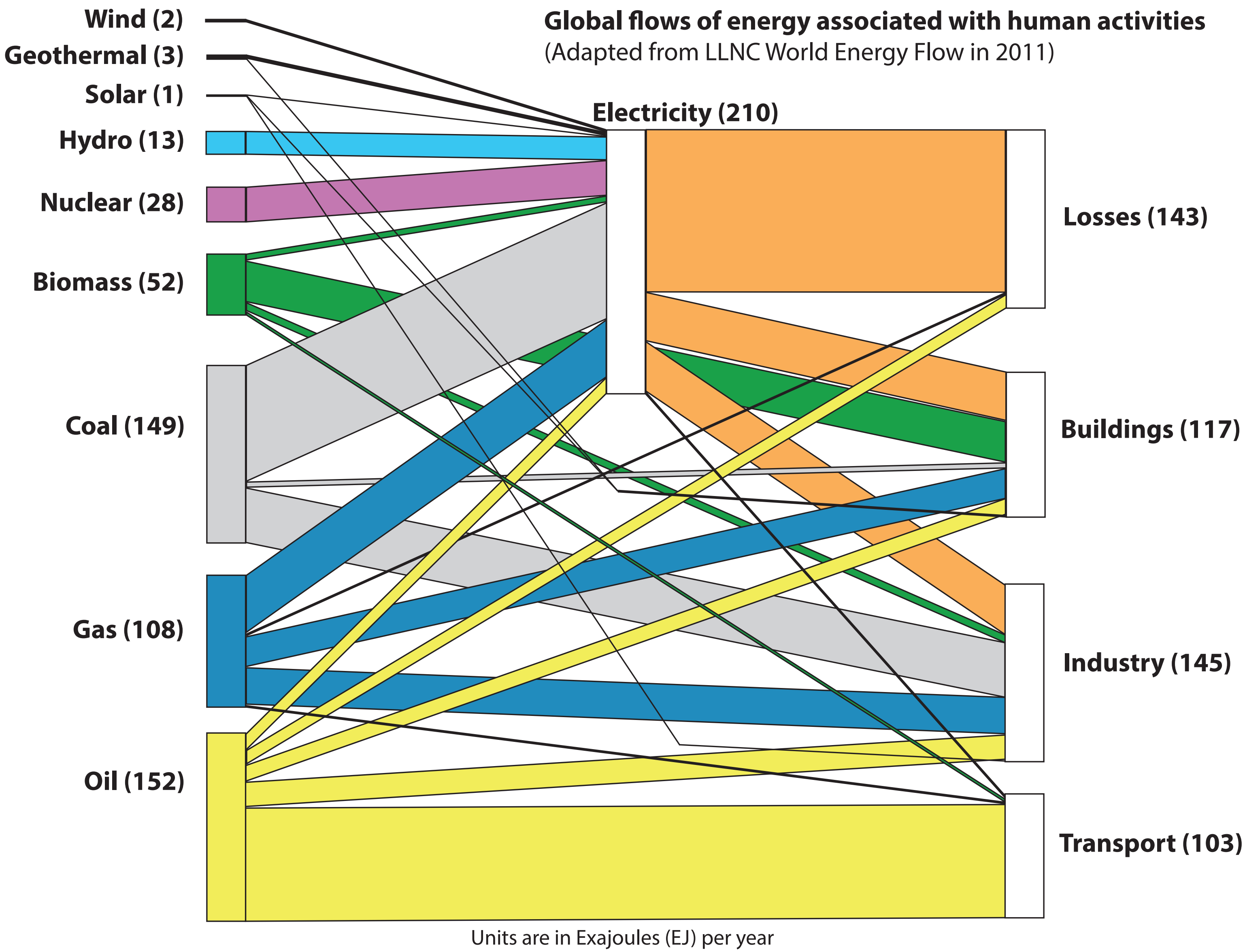
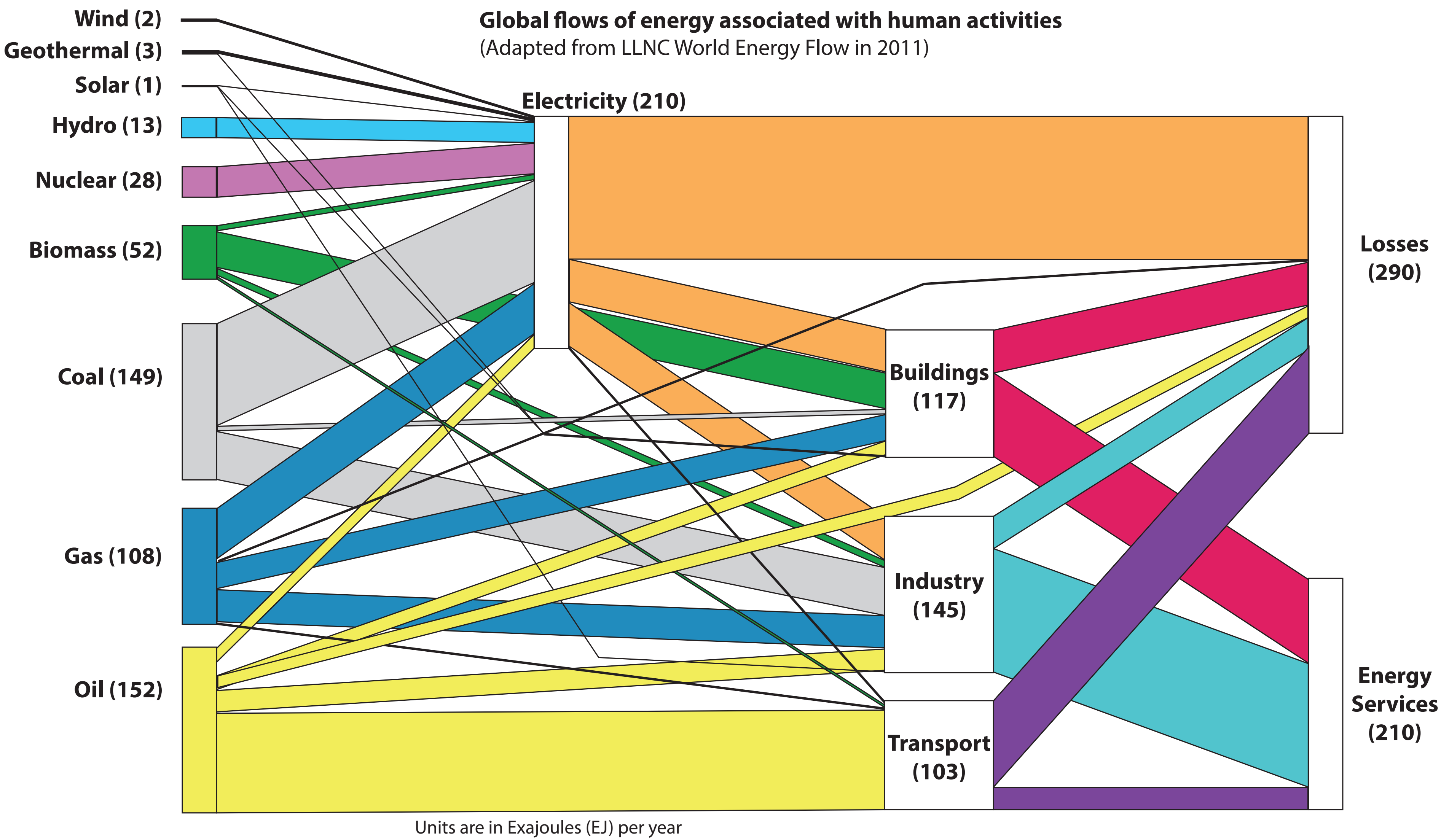


Global flows of energy associated with human activities
(Adapted from LLNC World Energy Flow in 2011)
Wind (2)
Geothermal (3)
Solar (1)
Hydro (13)
Nuclear (28)
Biomass (52)
Coal (149)
Gas (108)
Oil (152)
Electricity (210)
Losses (143)
Buildings (117)
Industry (145)
Transport (103)
Units are in Exajoules (EJ) per year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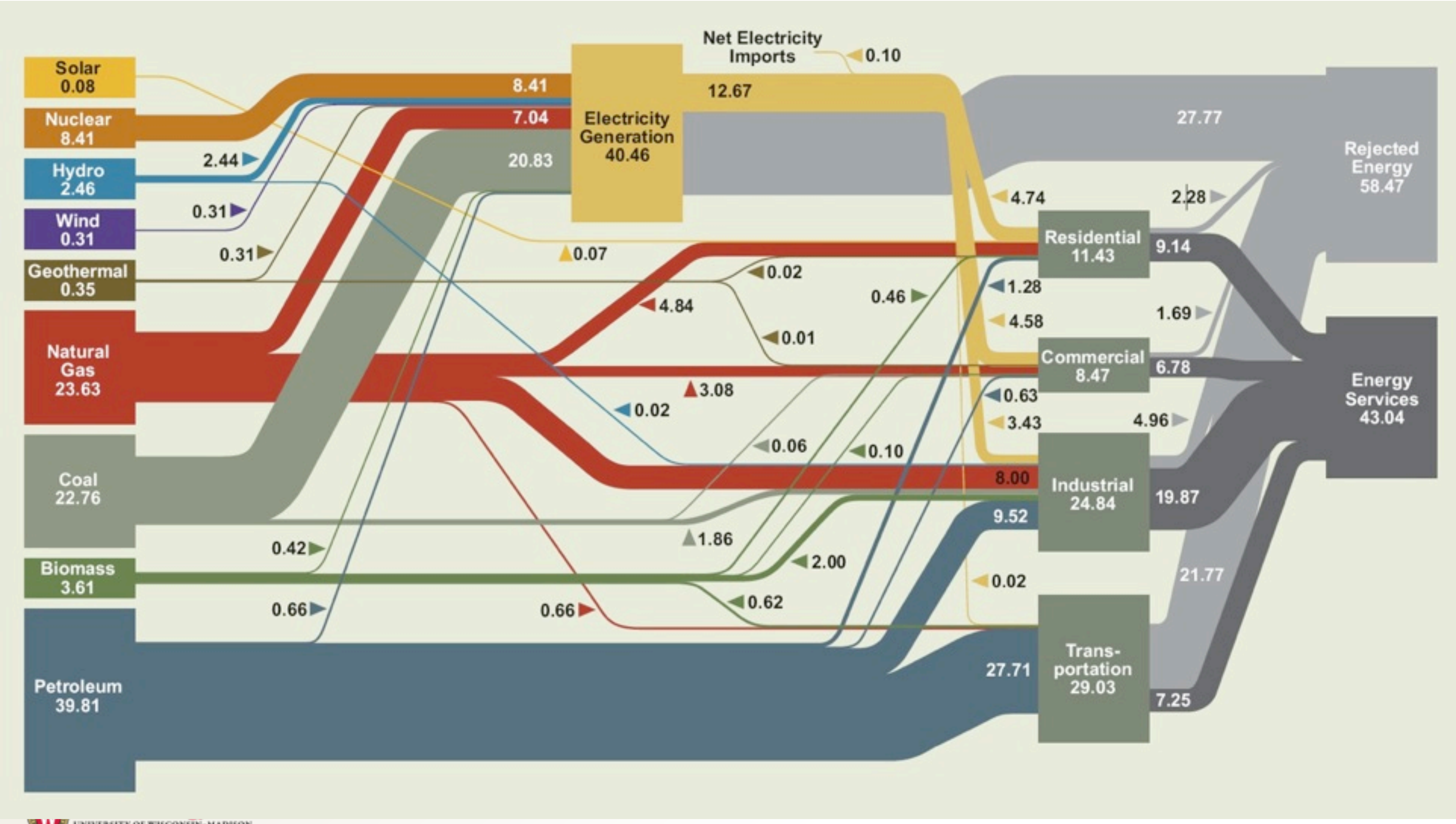
(Adapted from LLNC World Energy Flow in 2011)
Electricity (210)
Buildings (117)
Industry (145)
Transport (103)
Losses (290)
Energy Services (210)
Units are in Exajoules (EJ) per year

# United States Energy Flows

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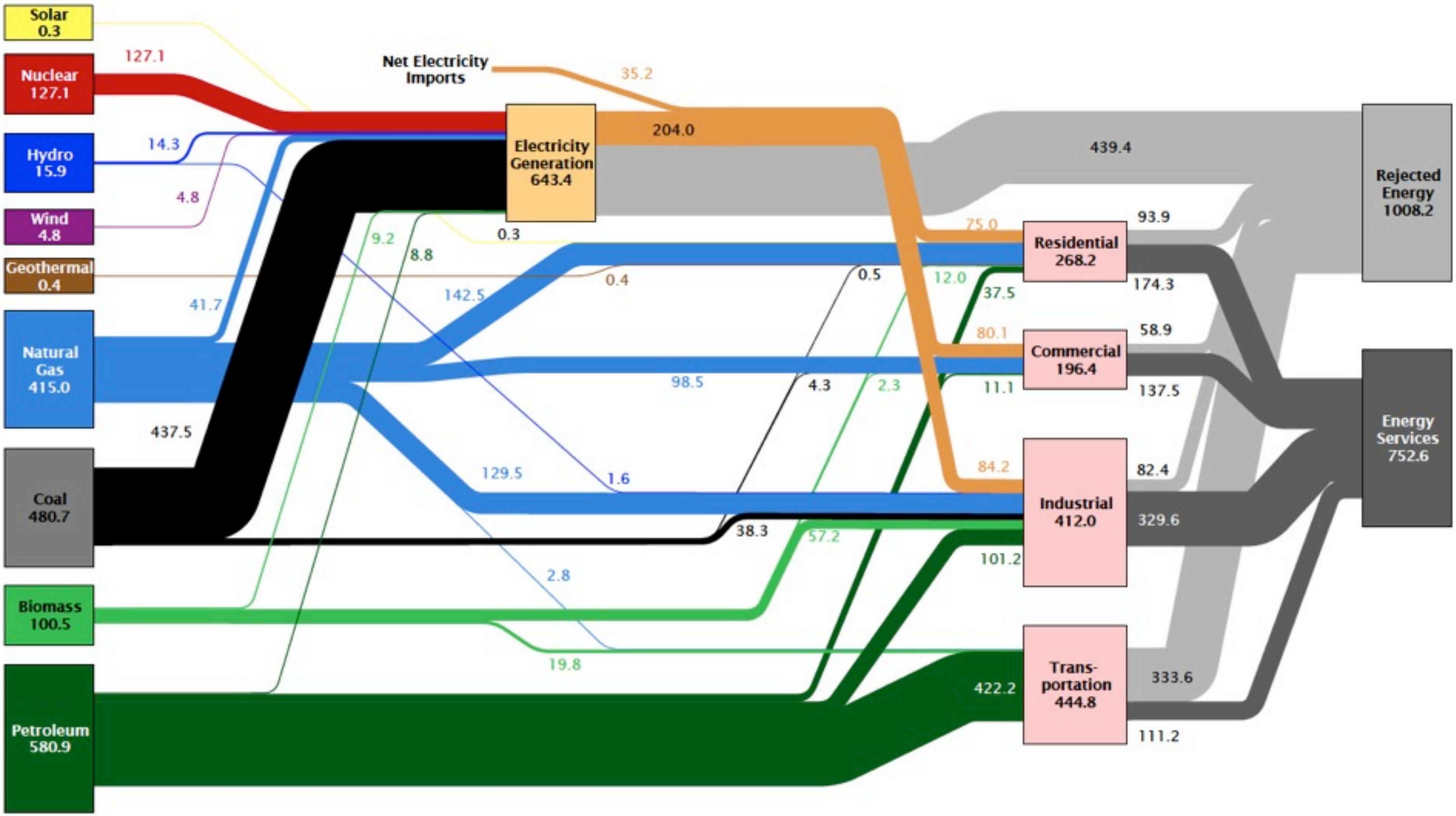
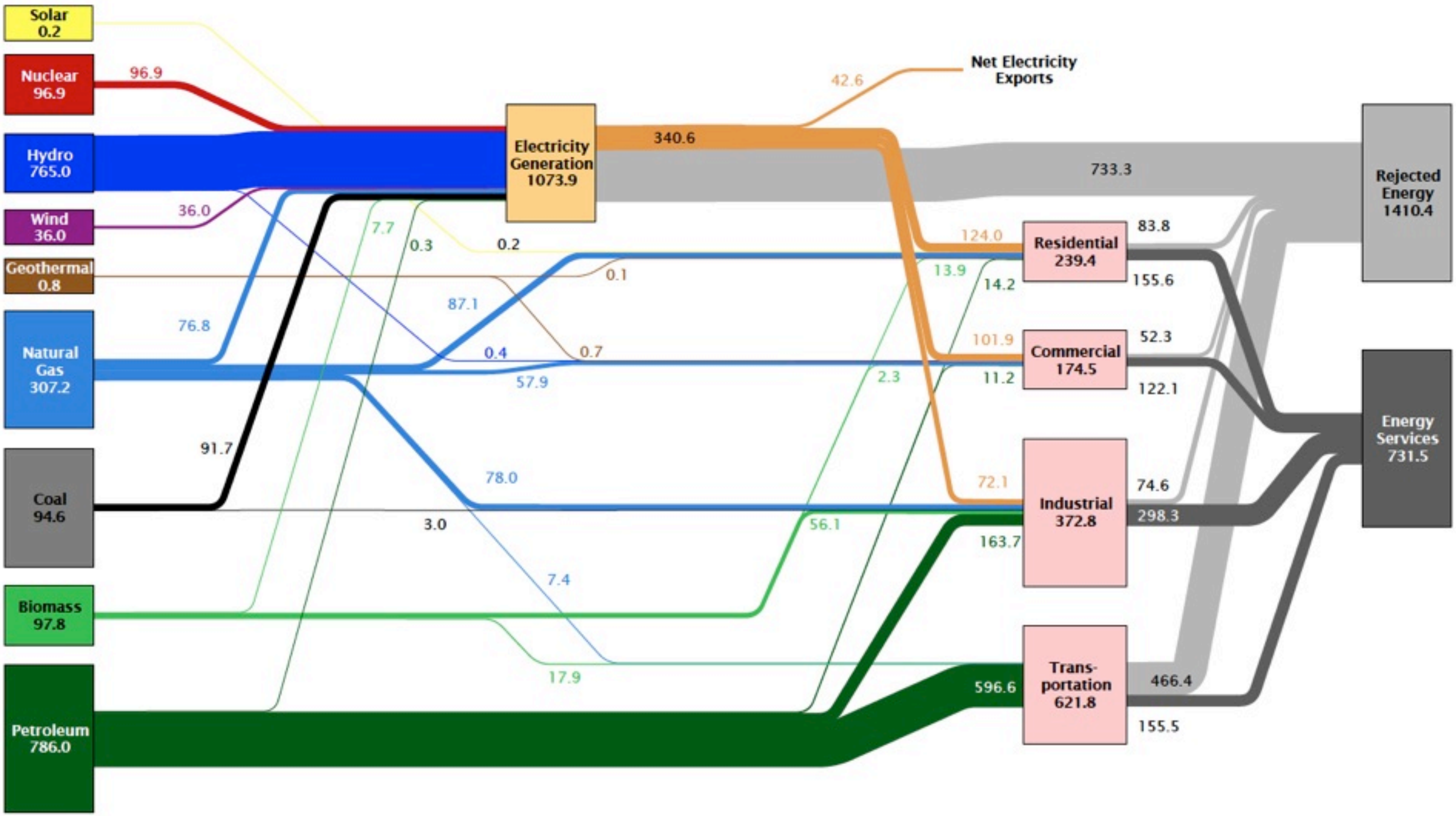
# Wisconsin Energy Flows




Source: LLNL 2010. Data is based on DOE/EIA-0214(2008), June 2010. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. Interstate and international electricity trade are lumped into net imports or exports and are calculated using a system-wide generation efficiency. End use efficiency is estimated as 65% for the residential, 70% for the commercial, 80% for the industrial sector, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

# Washington State Energy Flows

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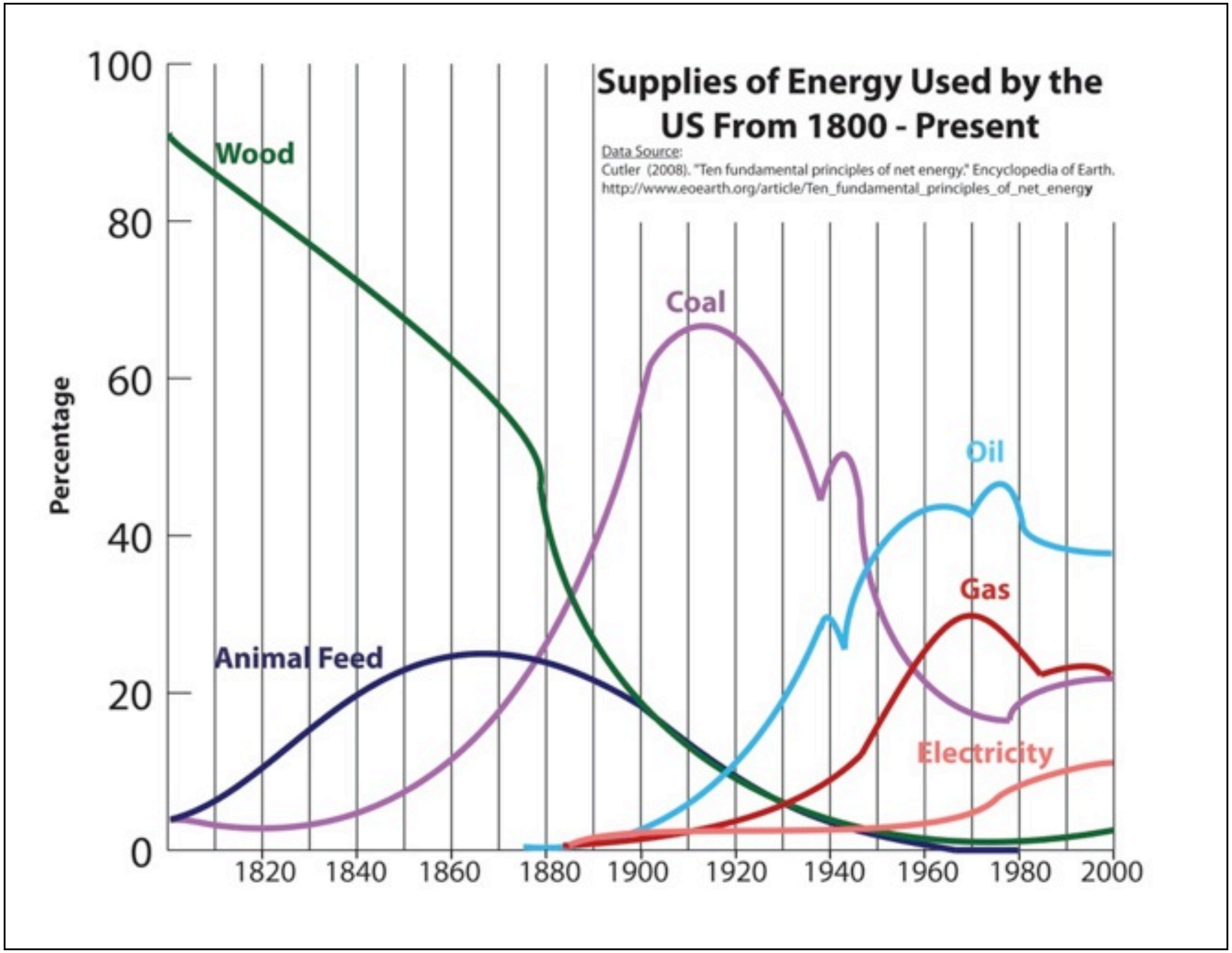
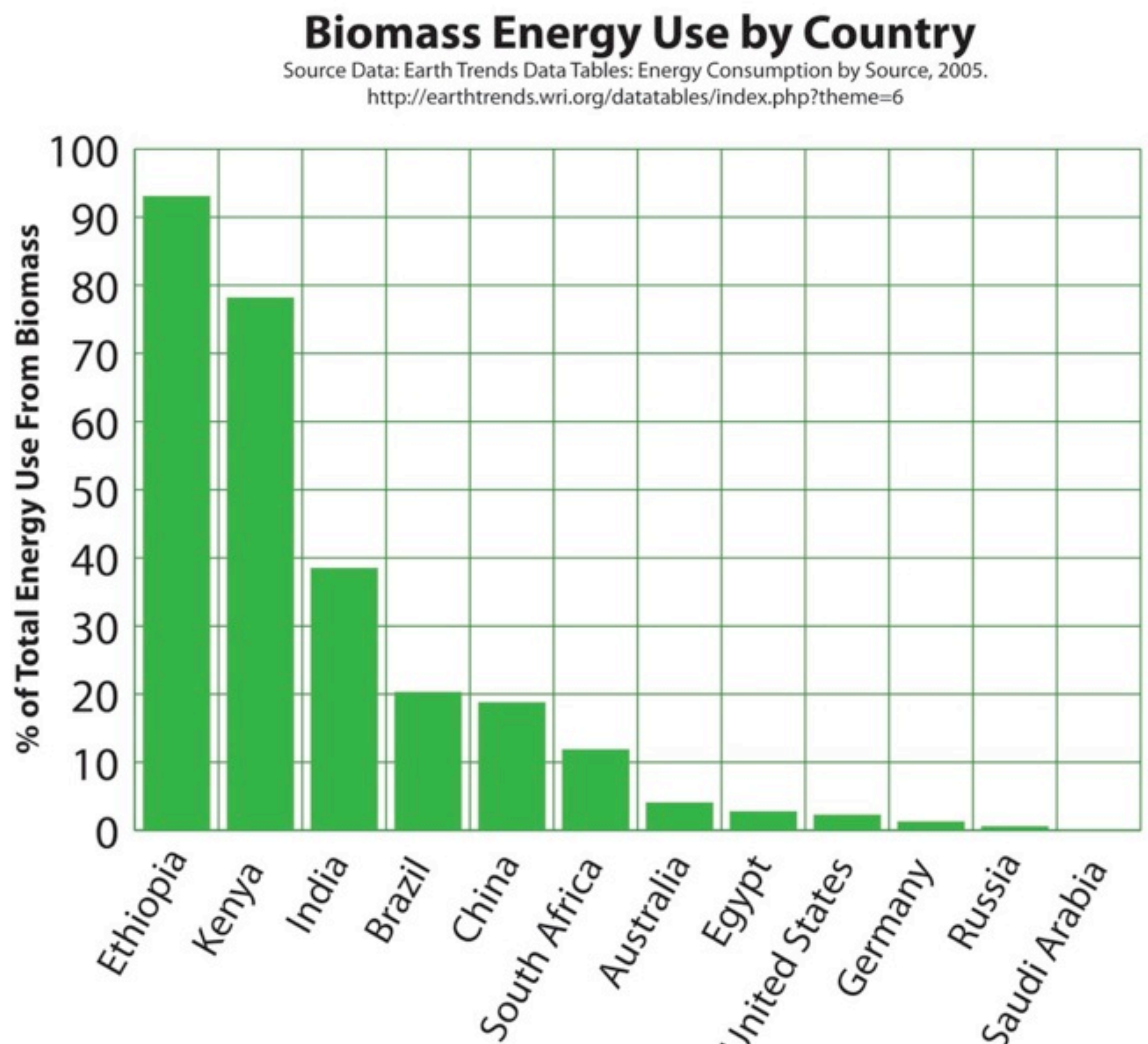
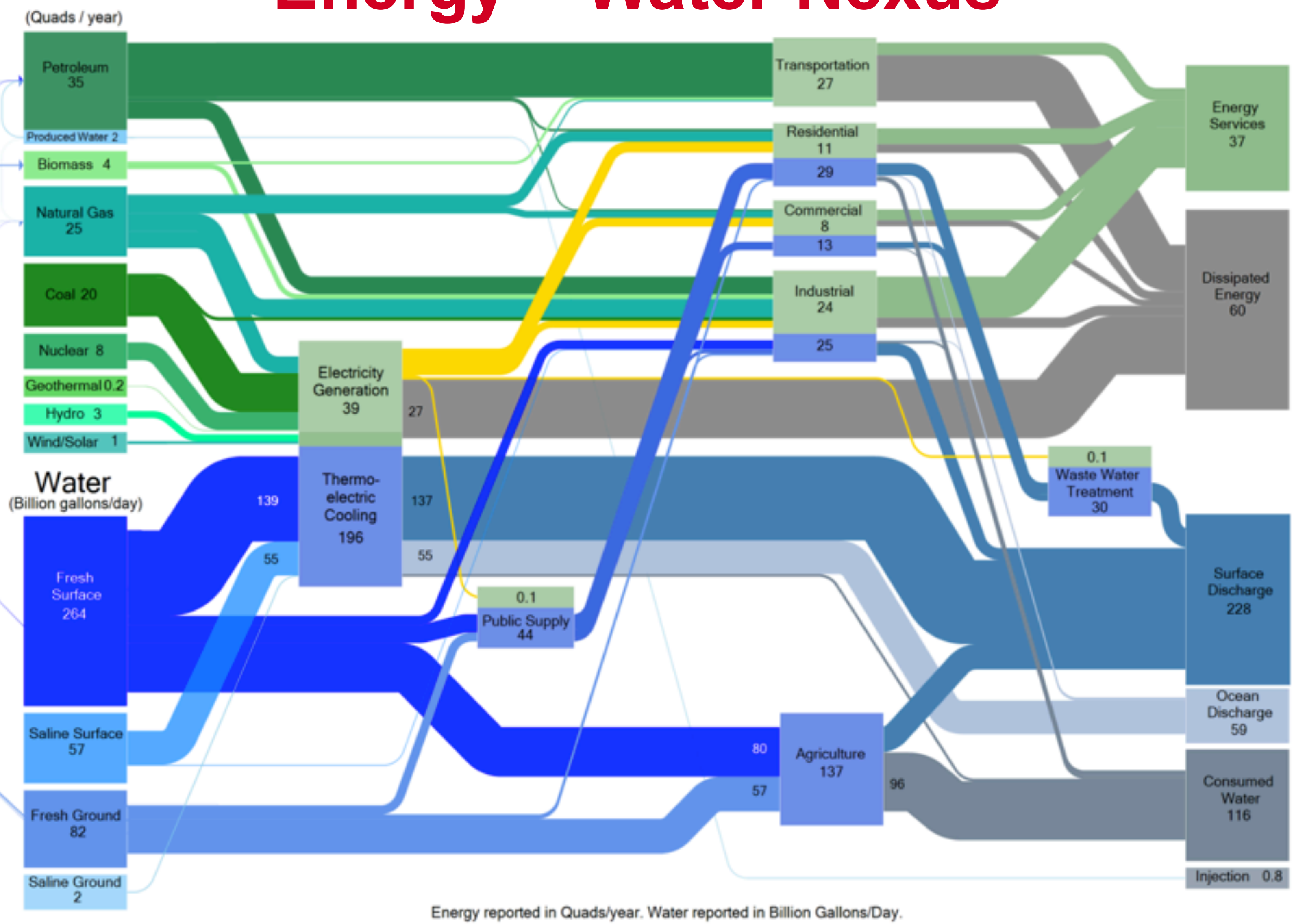
# U.S. Energy Sources: Historical



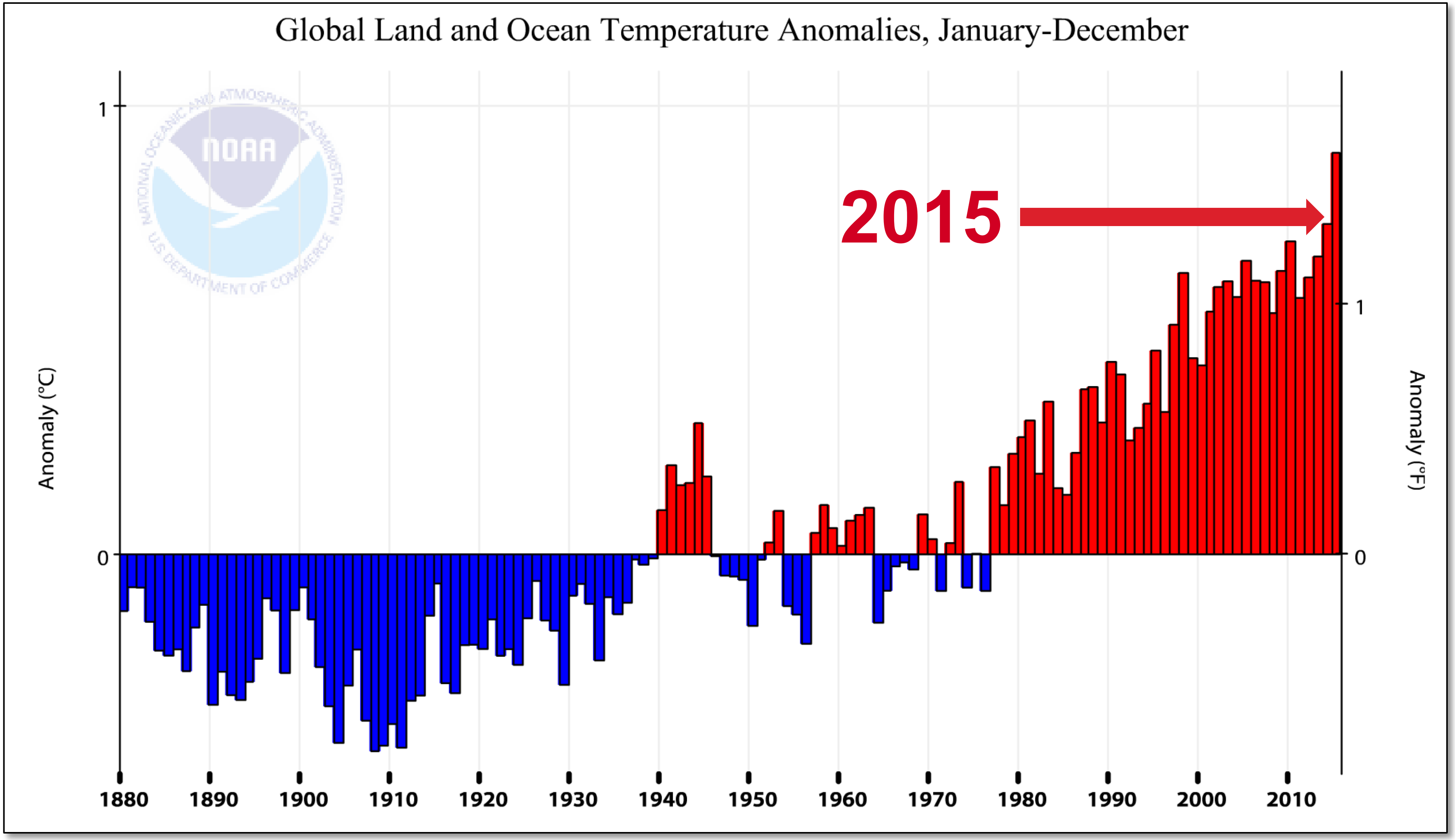

Biomass Energy Use by Country
Source Data: Earth Trends Data Tables: Energy Consumption by Source, 2005.
http://earthtrends.wri.org/datatables/index.php?theme=6
% of Total Energy Use From Biomass
100
90
80
70
60
50
40
30
20
10
0
Ethiopia
Kenya
India
Brazil
China
South Africa
Australia
Egypt
United States
Germany
Russia
Saudi Arabia

# Energy – Water Nexus



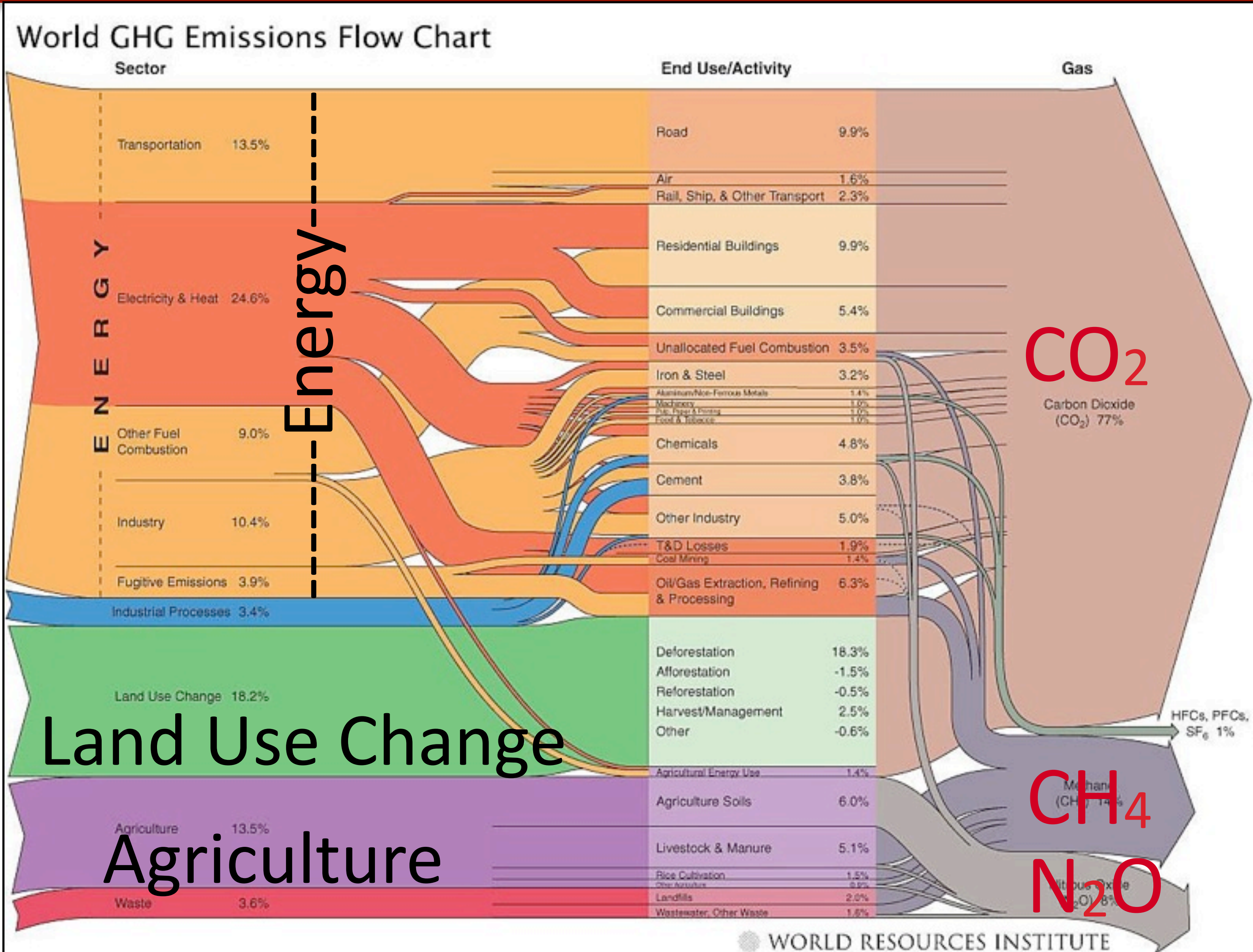

Hybrid Sankey diagram of 2011 U.S. interconnected water and energy flows.

*From: The Water-Energy Nexus: Challenges and Opportunties, DOE, June 2014*

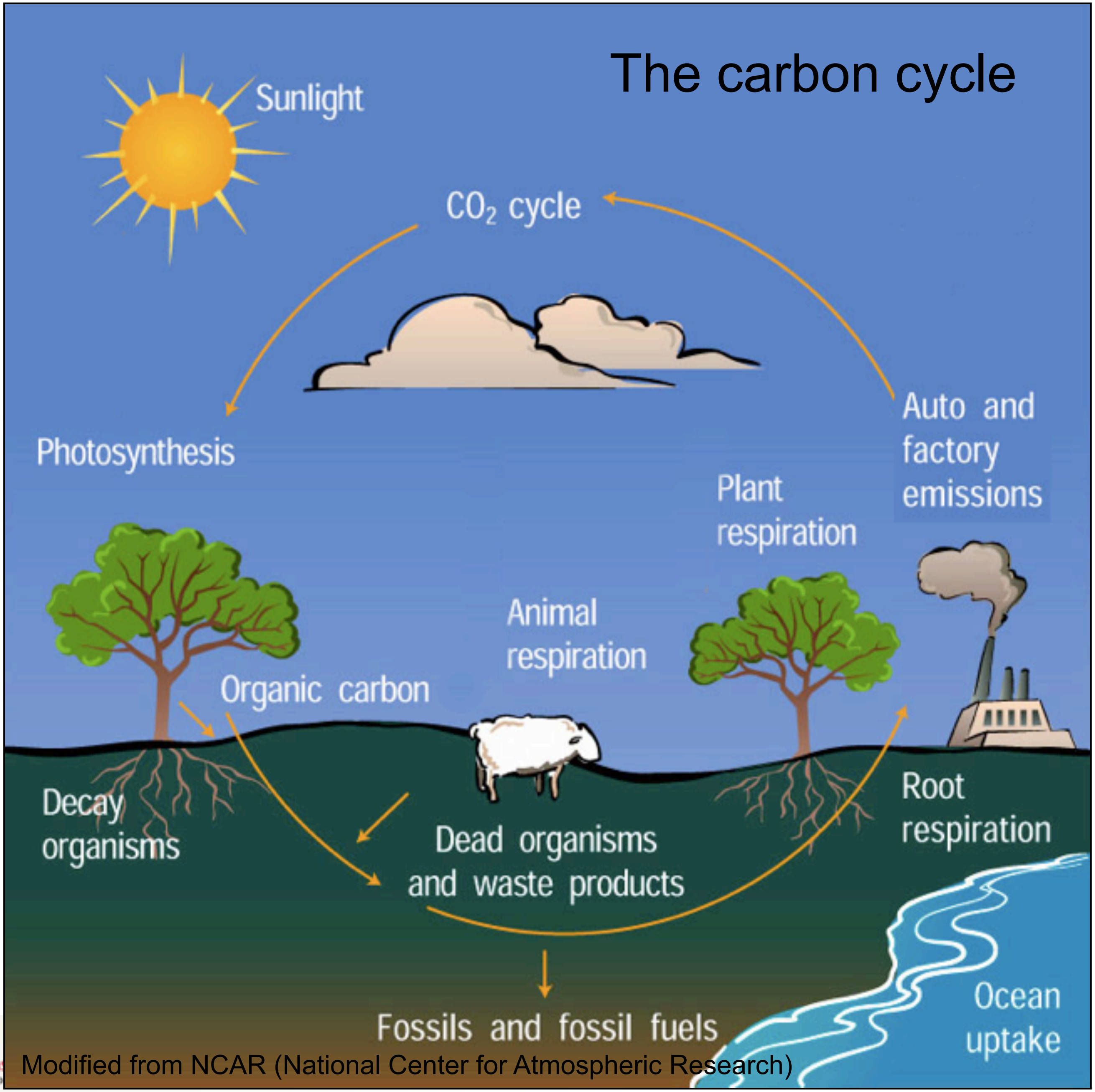



http://www.ncdc.noaa.gov/sotc/global/201513

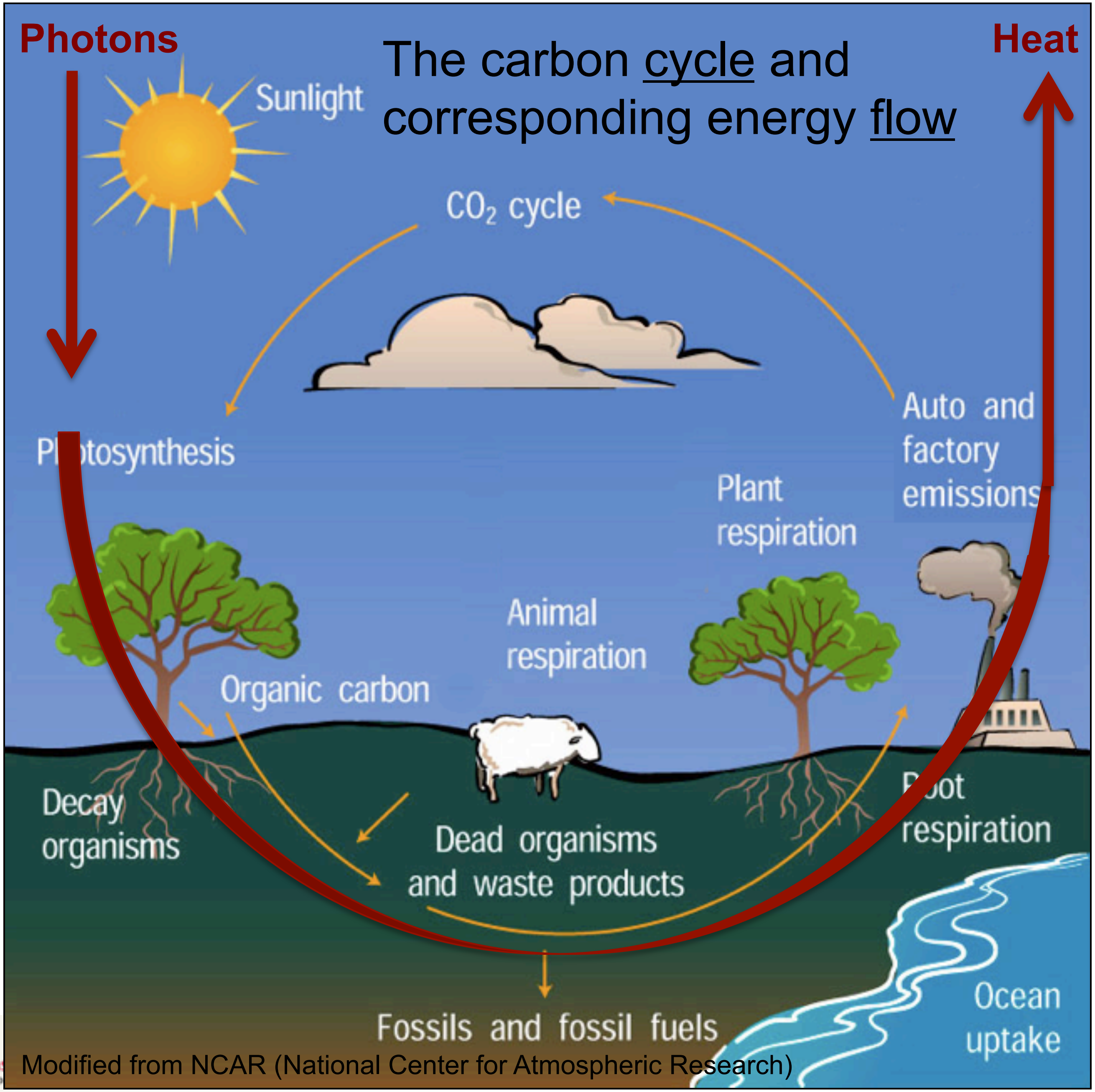
# Global Warming = Climate Change

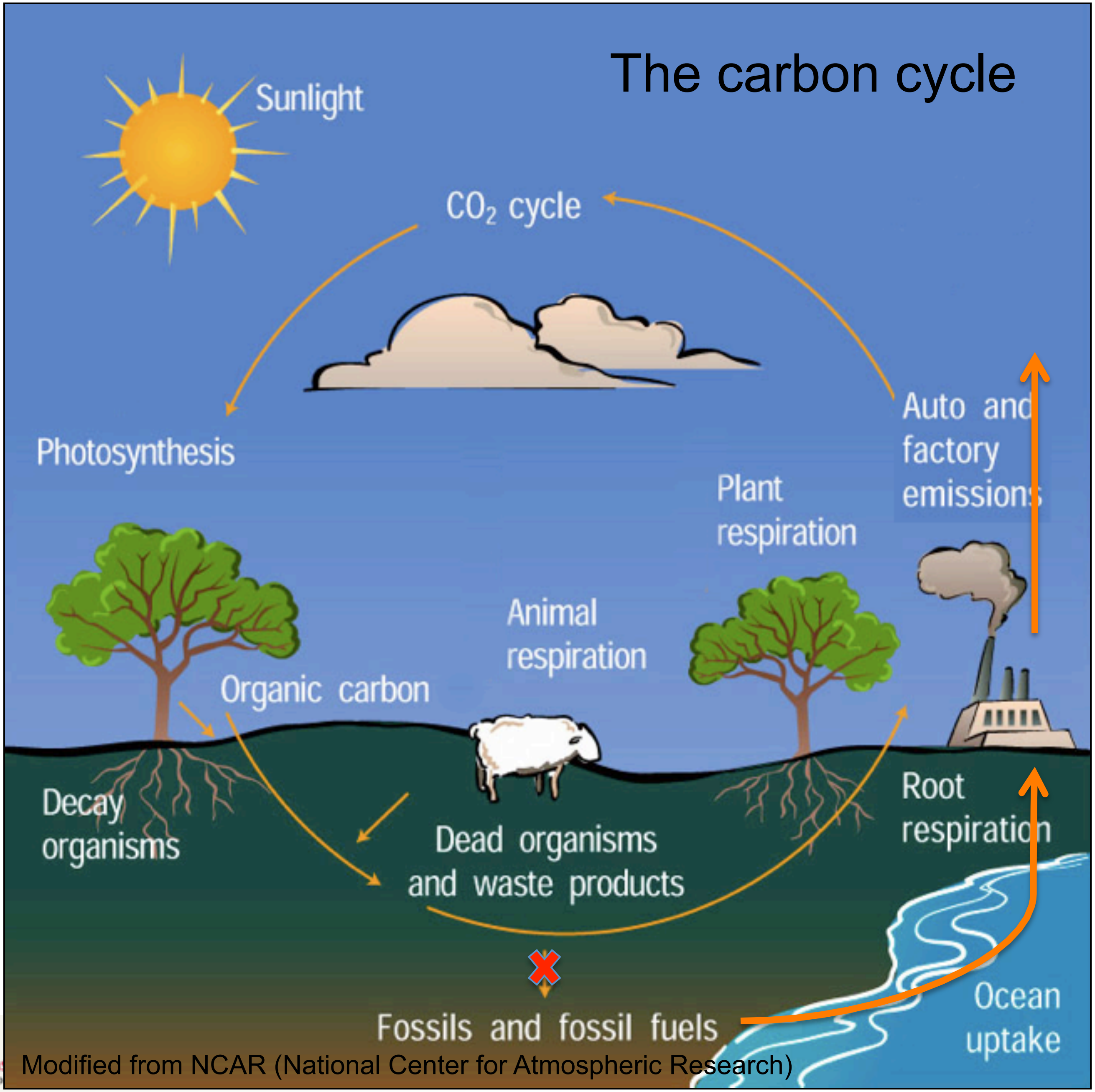


World GHG Emissions Flow Chart
Sector
End Use/Activity
Gas
ENERGY
Energy
Transportation 13.5%
Electricity & Heat 24.6%
Other Fuel Combustion 9.0%
Industry 10.4%
Fugitive Emissions 3.9%
Industrial Processes 3.4%
Land Use Change 18.2%
Land Use Change
Agriculture 13.5%
Agriculture
Waste 3.6%
Road 9.9%
Air 1.6%
Rail, Ship, & Other Transport 2.3%
Residential Buildings 9.9%
Commercial Buildings 5.4%
Unallocated Fuel Combustion 3.5%
Iron & Steel 3.2%
Aluminum/Non-Ferrous Metals 1.4%
Machinery 1.0%
Chemicals 4.8%
Cement 3.8%
Other Industry 5.0%
T&D Losses 1.9%
Coal Mining 1.4%
Oil/Gas Extraction, Refining & Processing 6.3%
Deforestation 18.3%
Afforestation -1.5%
Reforestation -0.5%
Harvest/Management 2.5%
Other -0.6%
Agricultural Energy Use 1.4%
Agriculture Soils 6.0%
Livestock & Manure 5.1%
Rice Cultivation 1.5%
Landfills 2.0%
Wastewater, Other Waste 1.6%
$CO_2$
Carbon Dioxide ($CO_2$) 77%
HFCs, PFCs, $SF_6$ 1%
$CH_4$
$N_2O$
WORLD RESOURCES INSTITUTE




Modified from NCAR (National Center for Atmospheric Research)


Photons
Heat
The carbon cycle and corresponding energy flow
Sunlight
CO₂ cycle
Photosynthesis
Auto and factory emissions
Plant respiration
Animal respiration
Organic carbon
Decay organisms
Dead organisms and waste products
Root respiration
Fossils and fossil fuels
Ocean uptake
Modified from NCAR (National Center for Atmospheric Research)




Modified from NCAR (National Center for Atmospheric Research)

# Today's Biofuel Ethanol Technology

**Conversion of sugar cane (glucose) or corn starch (glucose polymer) to ethanol**

Corn (kernels)

Starch

↓ *Heat and/or enzymes*

Glucose

↓ *Fermentation (microbes)*

Ethanol

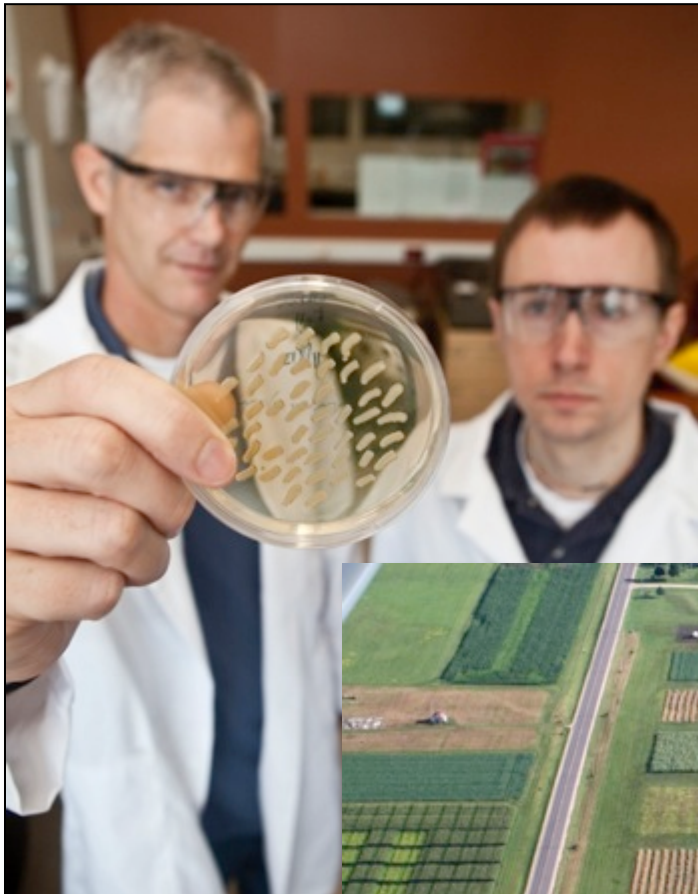
Sugar Cane

Glucose

↓ *Fermentation (microbes)*

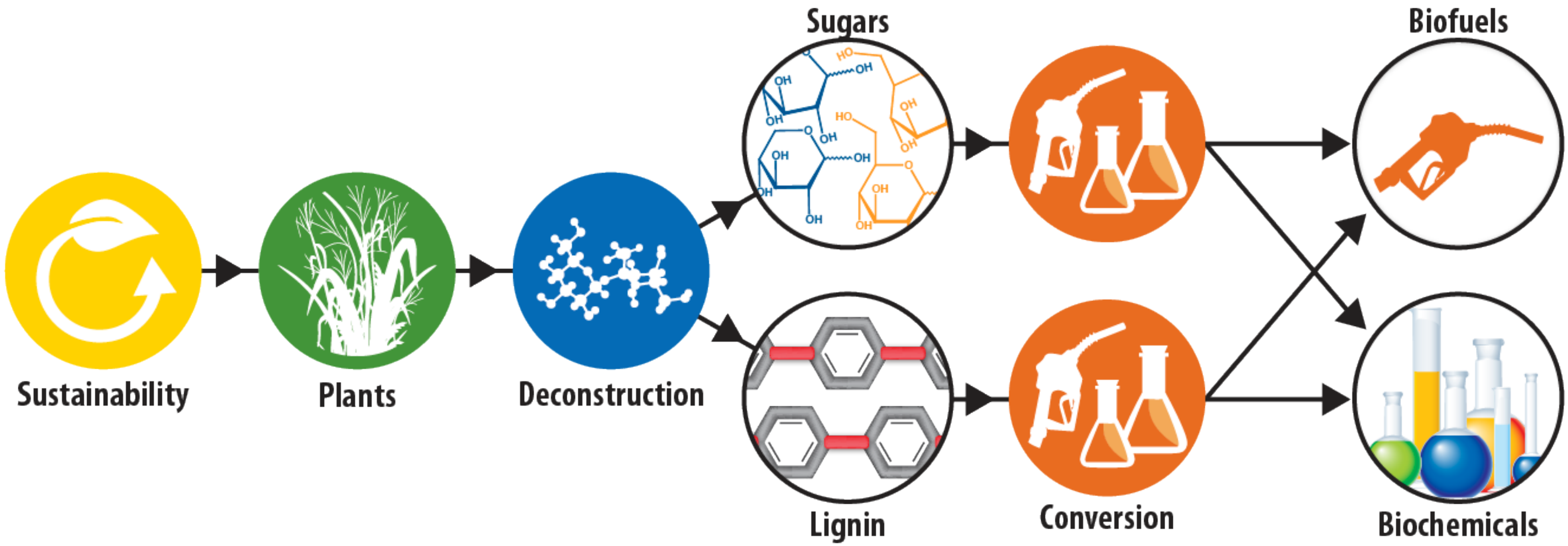
Ethanol

# The Mission of GLBRC



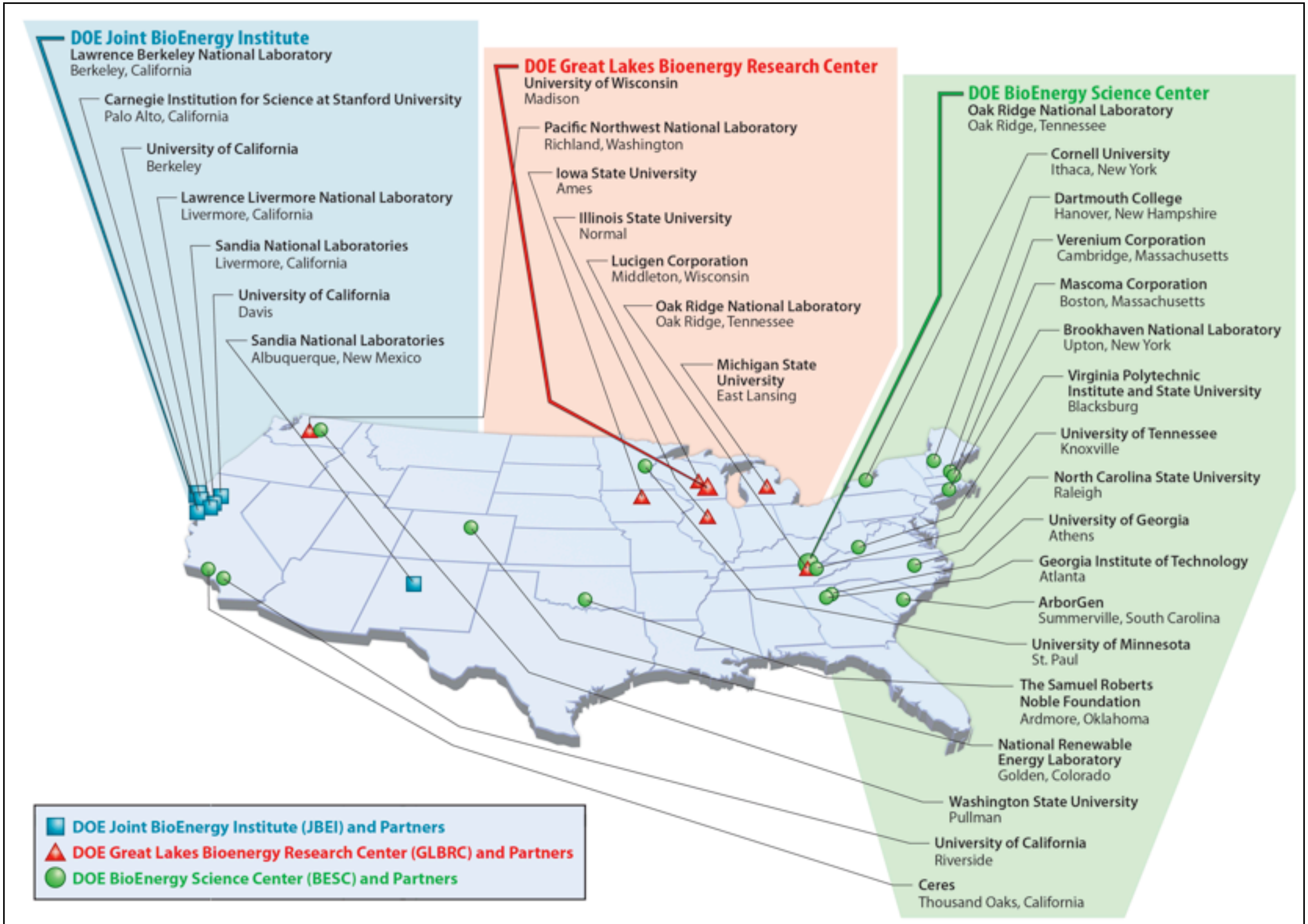
**To perform the basic research that generates technology to convert cellulosic biomass into sustainable biofuels.**

# Great Lakes Bioenergy Research Center

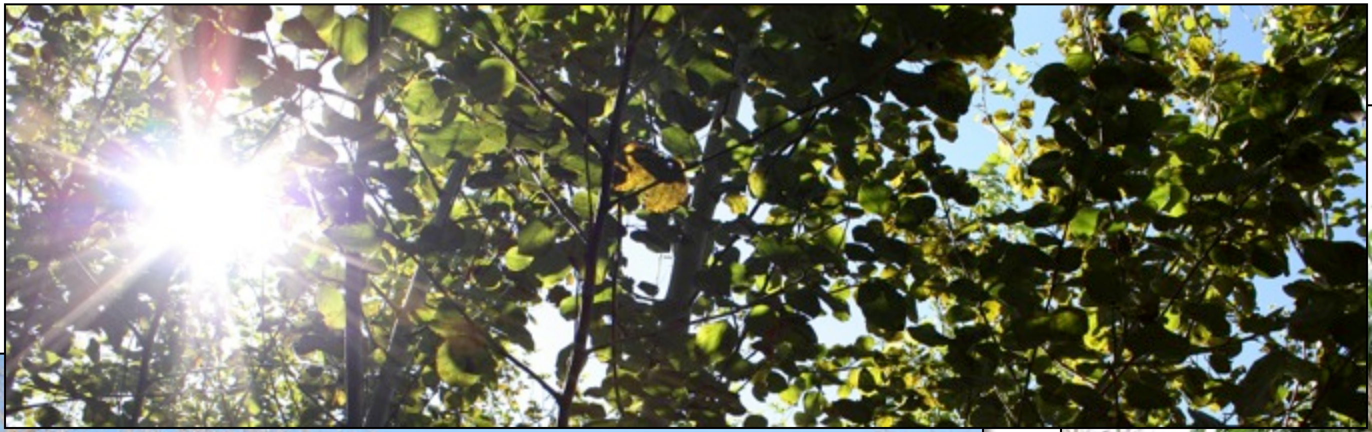



- Field (ecosystems, plants, microbes, air, water)
- Laboratory (molecular, genomic, atomic)
- Multi-scale modeling (molecules, cells, ecosystems & refineries)

# United States DOE Bioenergy Research Centers



# What is Cellulose?



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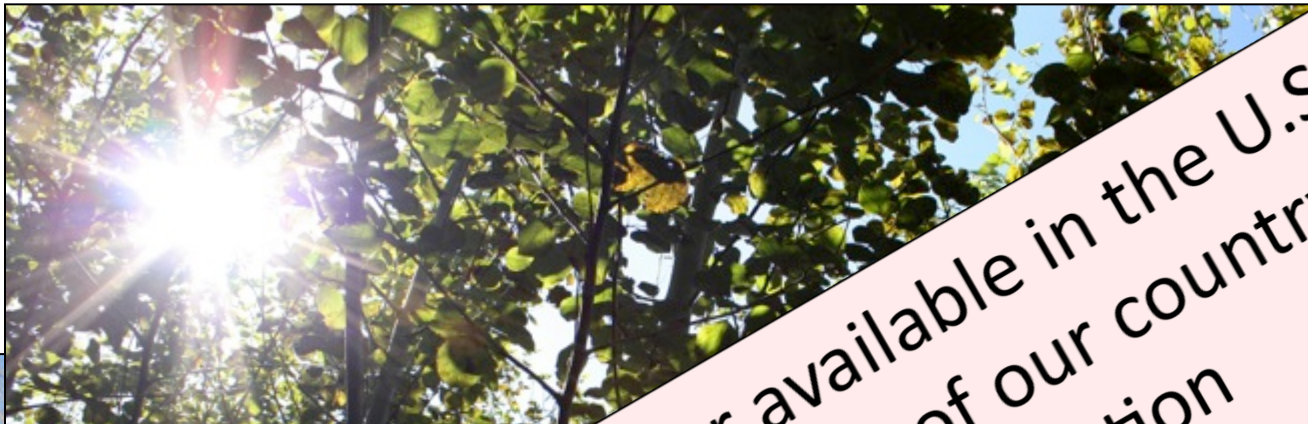
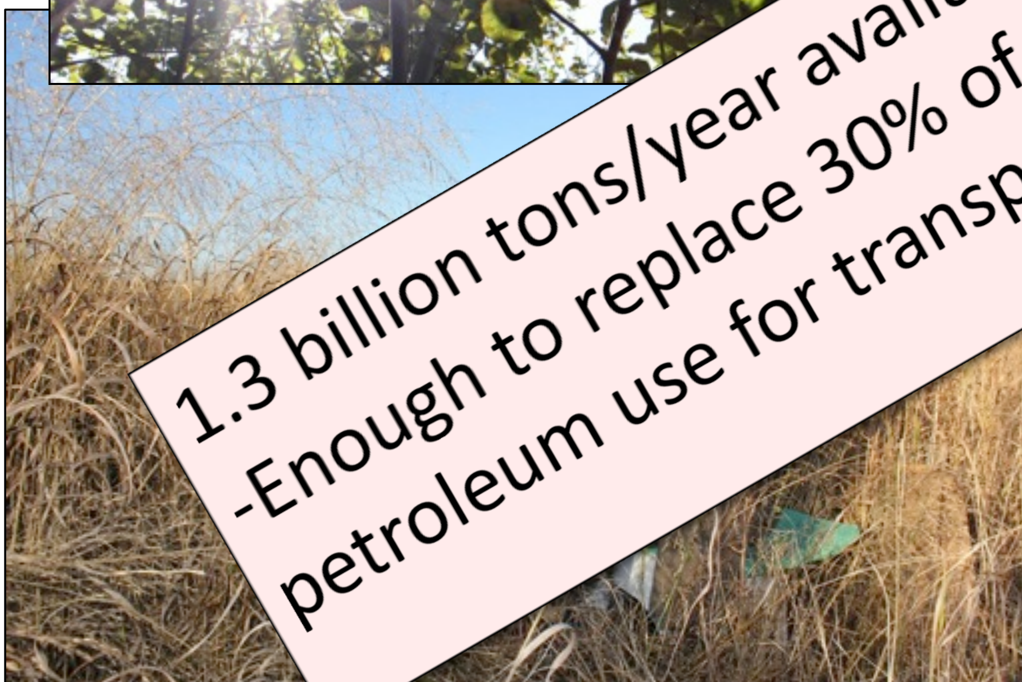
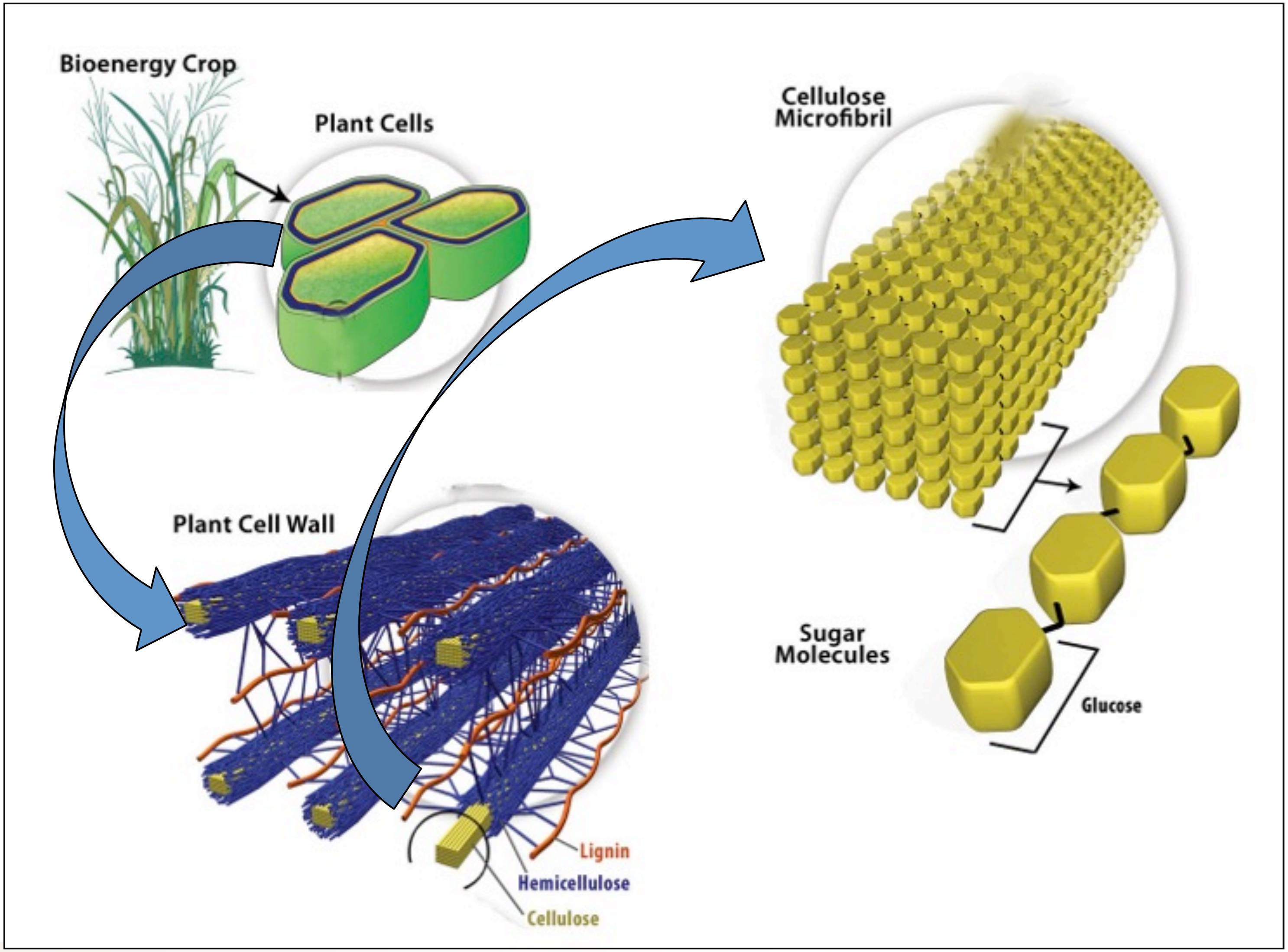


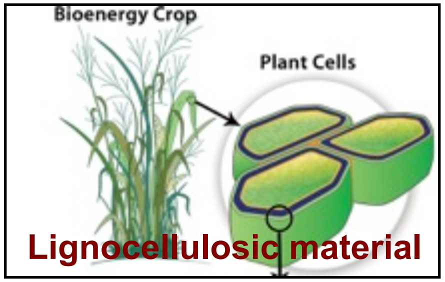


1.3 billion tons/year available in the U.S.
-Enough to replace 30% of our country's petroleum use for transportation

# What is Cellulose?



# Conversion of Cellulosic Plant Biomass to Fuels




*Today's technology*

Sugar Cane

Glucose

*Fermentation (microbes)*

Ethanol

Corn (kernels)

Starch

*Heat and/or enzymes*

Glucose

*Fermentation (microbes)*

Ethanol

*Tomorrow's technology*
(GLBRC)

**Plant biomass**

? *Pretreat (grind, heat, chemicals, pressure)*

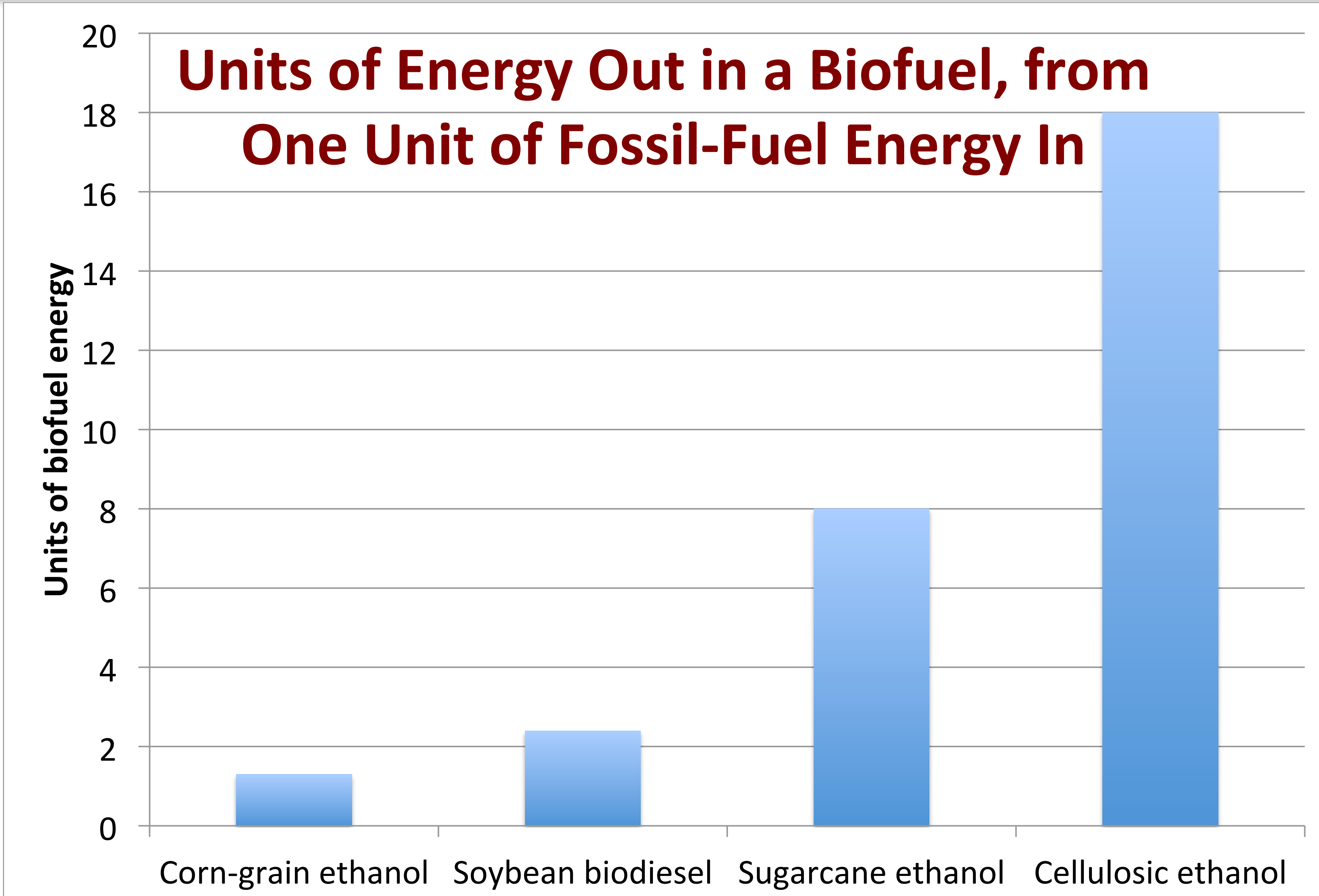
**"Loosened" cell wall material**
(cellulose hemicellulose, lignin)

? *Enzymes (cellulases, etc) or microbes*

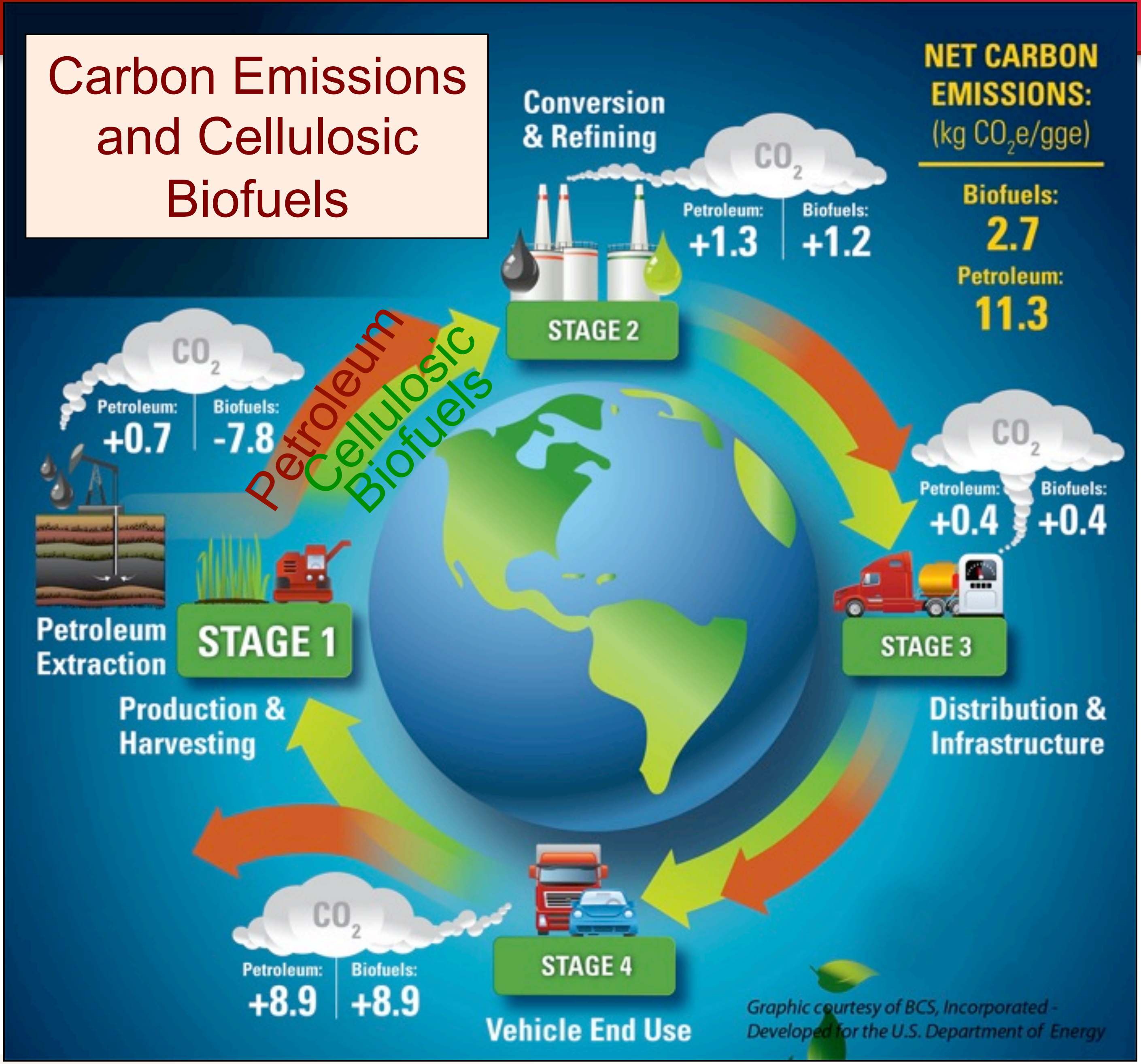
**Mixed sugars, etc.**
(glucose, arabinose, xylose, phenolics, etc.)

? *Fermentation (microbes) or catalysts*

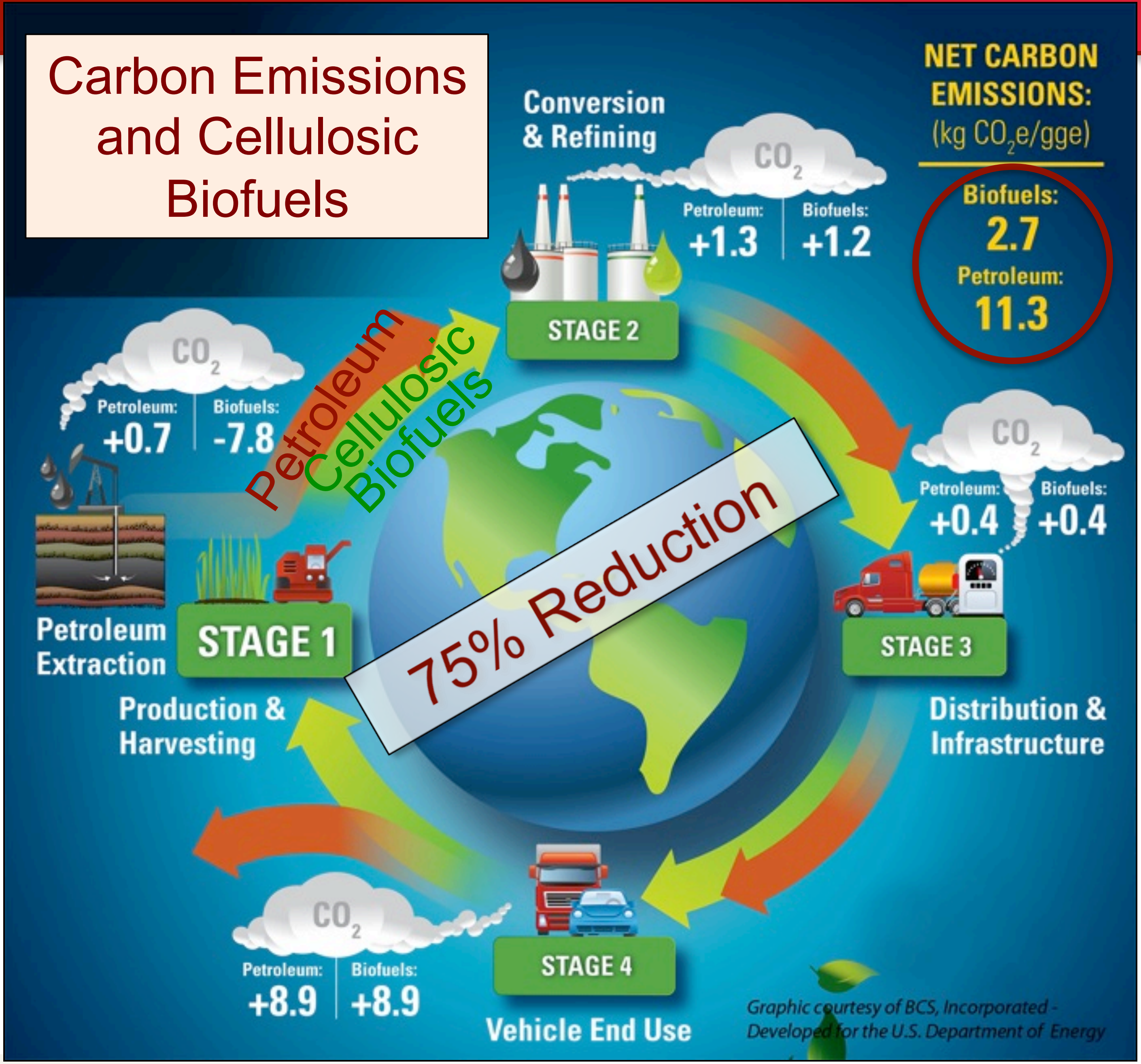
Ethanol (next generation fuel)


Units of Energy Out in a Biofuel, from
One Unit of Fossil-Fuel Energy In
Units of biofuel energy
20
18
16
14
12
10
8
6
4
2
0
Corn-grain ethanol
Soybean biodiesel
Sugarcane ethanol
Cellulosic ethanol

# Carbon Emissions and Cellulosic Biofuels

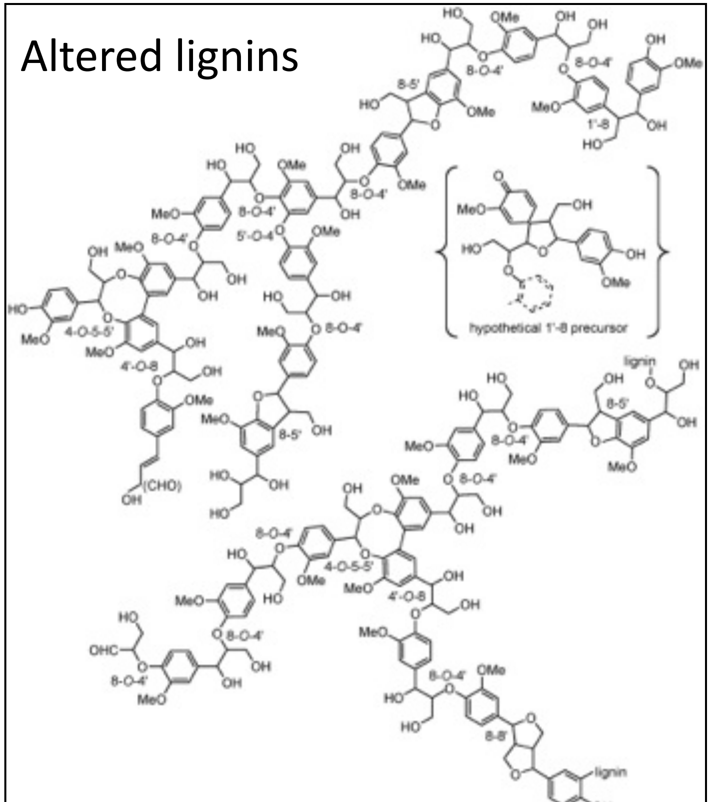


# Carbon Emissions and Cellulosic Biofuels



# Plant Breeding for Greater Biofuels Potential

Altered lignins

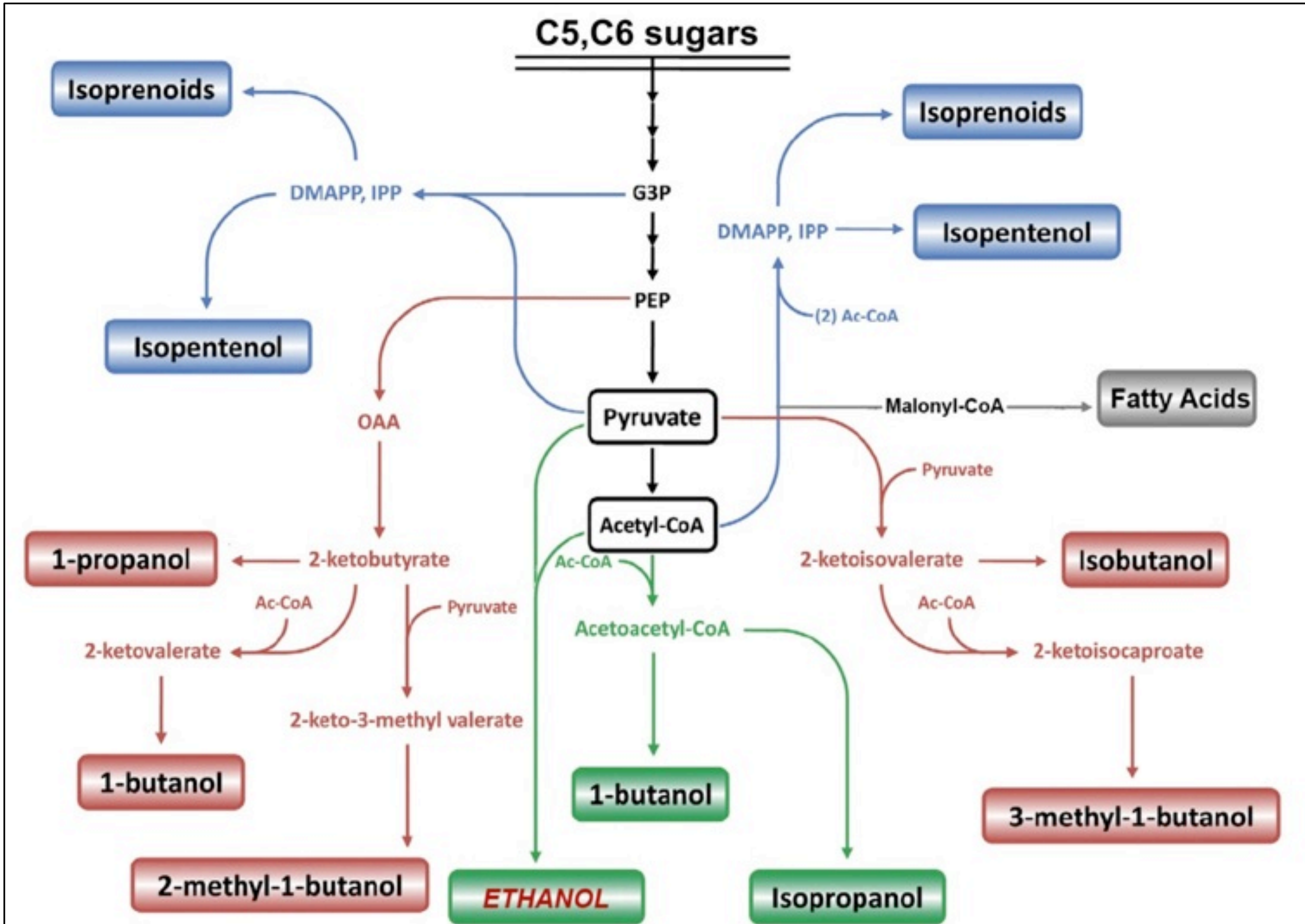


Genome Management Information System, Oak Ridge National Laboratory

Varieties of corn for bioenergy

# Bioprospecting - Thermophiles at Yellowstone

# Metabolic Pathways to a Diversity of Biofuels




*adapted from Connor & Liao, Curr. Op. Biotech., 2009.*

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# Questions?